Question 2:
Which computer displays were investigated during the project?

This study evaluated two types of computer display technologies: cathode ray tubes (CRTs) and liquid crystal displays (LCDs). In a life-cycle assessment (LCA), a "functional unit" is defined to delineate the functional characteristics of the products being evaluated and allow them to be evaluated on an equivalent basis. For this study, the functional unit was defined as one desktop computer display over its life. Data collected in this project were normalized to a display that meets the functional unit specifications presented in Table 2.1.

Table 2.1. Functional unit specifications

Specification	Measure
display size [a]	17" (CRT); 15" (LCD)
diagonal viewing area [a]	15.9" (CRT); 15" (LCD)
viewing area dimensions	12.8" x 9.5" (122 in^2) (CRT); 12" x 9" (108 in^2) (LCD)
resolution	1024 x 768 color pixels
brightness	200 cd/m^2
contrast ratio	100:1
color	262,000 colors

[a]An LCD is manufactured such that its nearest equivalent to the 17" CRT display is the 15" LCD. The viewing area of a 17" CRT is about 15.9 inches and the viewing area of a 15" LCD is 15 inches. LCDs are not manufactured to be exactly equivalent to the viewing area of the CRT.

In addition to LCDs, several other flat panel display technologies were considered for inclusion in the project; however, as these other technologies are not used for standard desktop computer displays (this study's functional unit), they were ultimately not included in the study. Each of the technologies included, CRTs and LCDs, is discussed in more detail below.

Cathode Ray Tube Display

CRT Technology

CRT monitors are a mature technology and are the current industry standard for desktop computer displays. The technology is the same as that for a television. CRT displays use high voltages to accelerate electrons toward a luminescent material (phosphor) that is deposited on a faceplate. The phosphor converts the kinetic energy of the electrons into light. The CRT must have excellent electrical insulating properties because the high voltages used to accelerate the electrons must be insulated from the external surfaces of the tube. The decelerating electrons produce X-rays, so the CRT must also be a good X-ray absorber. Leaded glass therefore surrounds the cathode ray tube to absorb the X-rays.

The major parts of the CRT display are a faceplate (glass panel), a shadow mask (also referred to as the aperture mask), a leaded glass funnel, and an electron gun with a deflection yoke. Various connectors, wiring, an implosion band, printed wiring boards, and the casing comprise most of the rest of the display. The overall project report, *Desktop Computer Displays: A Life-Cycle Assessment*, provides a detailed list of each part in the CRT assembly, the subassemblies that make up that part, and the materials in the manufacture of each component. To illustrate the level of detail examined, an example of this detailed materials list is presented in Table 2.2 for the tube -- just one component of the CRT display.

Table 2.2. CRT display components and materials (excerpt)

Component parts				Materials
Tube	Faceplate assembly	Phosphor-coated faceplate	Glass faceplate	Glass (1-2.5% PbO alkali/ alkaline earth aluminosilicate)
			Phosphors	ZnS, Y_2O_2S (powders): Sn, Si, K, Cd
			Photoresist	Polyvinyl alcohol
			Black matrix coating	Aquadag
			Lacquer coating	Mixture of alcohol and plastics
			Aluminum coating	Aluminum
		Internal electron shield		Aluminum
		Shadow mask assembly		Steel, Ni
	Frit (lead solder glass)			Lead oxide, zinc borate (- 70% PbO)
	Conductively coated funnel	Glass funnel		Leaded glass (- 24% PbO)
		Conductive coating		Aquadag (may also add iron oxide)
		Frit		PbO, zinc oxide, boron oxide
		Binder		Nitrocellulose binder, amyl acetate
	Neck	Neck glass		Leaded glass (30% PbO alkali/alkaline earth silicate)
		Deflection yoke		Cu, ferrite
		Base & top neck, rings		Polystyrene
		Brass ring, brackets		Brass
		Rubber gaskets		Rubber
		Screws, washers		Zn-plated steel
		Neck clamp		Steel
		Insulating rings		Polysulphone
		Neck printed wiring board		Misc. electronics and resin board
	Implosion band			Steel

CRT Manufacturing

The traditional CRT manufacturing process is generally composed of the steps shown in Figure 2.1.

Figure 2.1. CRT manufacturing process

Glass fabrication
↓
Faceplate (screen) preparation
↓
Shadow mask fabrication/assembly
↓
Funnel preparation
↓
Bulb joining
↓
Electron gun fabrication
↓
Final assembly

Glass fabrication. The manufacturing process of the CRT monitor involves first preparing the glass. In glass manufacturing, raw materials (e.g., sand, soda ash, limestone, boron) are converted to a homogeneous melt at high temperatures and then formed into the panel (the faceplate on the front of the CRT) and the funnel (the back half of the CRT vacuum shell).

Faceplate preparation. The faceplate, also referred to as a screen or panel, is coated with a conductive material known as aquadag. The aquadag acts as an anode, attracting the electrons emitted from the electron guns. Luminescent phosphor materials are also applied to the inside surface of the faceplate. Using photolithography, the phosphor is applied in a pattern of dots or stripes where red, green, and blue phosphors are deposited in subsequent steps. The result is a patterned luminescent screen with the emissive elements separated by non-reflecting material. A lacquer coating is applied to the phosphor-coated glass to smooth and seal the inside surface of the screen, and an aluminum coating is added to enhance brightness.

Shadow mask fabrication and assembly. The shadow mask makes color images possible as electrons pass through the mask before hitting the precisely located colored regions of the faceplate. The shadow mask is a thin steel panel with a mask pattern of either round or slotted openings applied through photolithography. The flat mask is fitted to the contour of the faceplate and supported in the faceplate on a heavy frame. Alignment fixtures and an internal magnetic shield are added to complete the faceplate assembly.

Funnel preparation. The funnel provides the back half of the vacuum shell and electrically connects the electron gun and the faceplate to the anode button (a metal connector button in the funnel provided for attachment of the power supply). A conductive coating similar to the type used on the faceplate is applied to the inner surface of the glass funnel. Frit (solder glass) is applied to the edge of the funnel to be joined with the faceplate.

Bulb joining. The faceplate assembly is placed on the fritted edge of the funnel in a fixture that carries the two halves in precise alignment through a high temperature oven, where the frit is cured. The resulting assembly is a vacuum tight bulb, ready to receive the electron gun and to be evacuated to become a finished CRT.

Electron gun fabrication. The electron gun is an assembly of glass and a number of electrostatic electrodes made of steel. The electrodes, along with cathodes, ribbon conductors, and electrical feed-through pins are heated to embed the metal parts in the glass.

Final assembly. The frit-sealed bulb assembly and the electron gun assembly are joined by fusing a glass stem on the electron gun with the neck tubing in a machine that melts the two glasses together in precise alignment. Final steps are conducted to remove the air from the CRT to form a vacuum, before the entire monitor is assembled with other necessary parts (e.g., printed wiring boards, power cord, casing).

Liquid Crystal Display

LCD Technology

The two most common types of LCDs are passive matrix (PMLCD) and active matrix (AMLCD). This project focused on AMLCDs because PMLCDs are used primarily for low-end products (e.g., products that cannot perform video applications) and are forecasted to decline to less than one percent of the LCD desktop display market by 2002. The most common type of AMLCD, and the one that meets the functional unit specifications of this project, is called an amorphous silicon thin-film transistor active matrix LCD.

In general, an LCD is composed of two glass plates surrounding a liquid crystal material that filters external light. LCDs control the color and brightness of each pixel (picture element) individually, rather than from one source, such as the electron gun in the CRT. The orientation of the liquid crystal molecules either allows or does not allow light from a backlight source to pass through the display cell. When no electrical current is present, the liquid crystals align themselves parallel to an alignment layer on the glass. When a current is applied, the liquid crystals turn perpendicular to the glass. The combination of the alignment layer, electrical charge, and polarizers that are laminated to the glass panels determine the on or off state of the LCD cell. The backlight supplies the light source for the display and generally has fluorescent tubes that contain small amounts of mercury vapor. Because the LCD technology essentially regulates passage of a backlight through the display, LCDs are considered non-emitting display technologies. CRTs, on the other hand, emit electrons to illuminate appropriate phosphors and are considered to be emitting displays.

LCD Manufacturing

The LCD manufacturing process is more complex than the CRT process in terms of the types of materials used and how the process steps are completed. A general overview of the manufacturing process is shown in Figure 2.2 and described below.

Figure 2.2. LCD manufacturing process

Glass fabrication
⇩
Front panel patterning
⇩
Rear panel patterning
⇩
Display cell assembly
⇩
Module assembly

Glass fabrication. Molten glass (e.g., soda lime or borosilicate glass) is prepared into flat substrates. The glass sheets are trimmed to the required size and cleaned, which is a critical step in reliable manufacturing.

Front panel patterning. The front panel electrode is created by sputtering indium tin oxide onto the glass. Next, a black matrix and red, green, and blue color filters is deposited and patterned (using a photolithography process) onto the panel. The black matrix creates a border around the color filters for contrast. The color filter process results in a non-uniform surface, so a layer of polyimide is added to create a planar surface. The last material added to the front panel is an alignment layer, which is a polyimide applied by roll coating and then rubbed to the desired molecular orientation.

Rear panel patterning. The rear panel is where the transistors are created, requiring more complex steps than the front panel. In the case of LCDs, the fast response speed required for computer displays is achieved by having a switch at each pixel, which is the basis for active-matrix addressing. This switch is a transistor that basically consists of a gate, source and drain, and channel. Electrons flow through the channel between the source and drain when voltage is applied to the gate. There is an insulating layer between the gate the source/drain region, referred to as a dielectric. The gate metal is applied first to the glass substrate and patterned. Next, a silicon-based dielectric, channel, and a doped silicon layer are applied and patterned as needed. The pixel electrode is formed by sputtering indium tin oxide (also used to create the front panel electrode). The source/drain metal is sputtered and patterned, and a contact is formed between this layer and the doped silicon layer. The substrate is cleaned and a thin polymer alignment layer is deposited onto the surface. This layer is then rubbed in the direction desired for the liquid crystal orientation.

Display cell assembly. At this stage of the process, the color filter substrate (front glass) and the transistor substrate (rear glass) are joined with an adhesive seal material. Before sealing the two substrates, spacers are deposited to maintain a precise gap of five to ten micrometers between the two surfaces. The substrates are aligned and laminated using heat and pressure. Liquid crystal material is then injected into the small space in between the substrates. The last step in the display cell assembly is attaching polarizers (from rolls or precut sheets) to the outside of each glass panel.

Module assembly. The module assembly step includes attaching the backlight unit, which is the light source for the LCD. A typical desktop unit has four backlights, which are placed around the edges of the display. The light projects across a diffuser screen to provide uniform illumination. The printed wiring boards, the power supply assembly, and the plastic cover and stand are added to make an assembled monitor.